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(21) International Application Number: PCT/GB97/02139 (22) International Filing Date: 11 August 1997 (11.08.97) (30) Priority Data: 9616853.9 10 August 1996 (10.08.96) GB (71) Applicant (for all designated States except US): VORGEM LIMITED [GB/GB]; 4 St. Margaret's Loan, Dunblane, Perthshire FK15 0DE (GB). (72) Inventors; and (75) Inventors/Applicants (for US only): HOLBROOK, Mark, Burton [GB/GB]; 4 St. Margaret's Loan, Dunblane, Perthshire FK15 0DE (GB). BECKMANN, William, George [GB/GB]; 4 St. Margaret's Loan, Dunblane, Perthshire FK15 0DE (GB). HICKS, Simon, Eric [GB/GB]; University of Glasgow, Dept. of Electronics and Electrical Engineering, Glasgow G12 8QQ (GB). WILKINSON, Christopher, David, Wicks [GB/GB]; University of Glasgow, Dept. of Electronics and Electrical Engineering, Glasgow G12 8QQ (GB). (74) Agent: MURGITROYD & COMPANY; 373 Scotland Street, Glasgow G5 8QA (GB).		(81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GE, GH, HU, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, US, UZ, VN, YU, ZW, ARIPO patent (GH, KE, LS, MW, SD, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG). Published <i>With international search report.</i>
(54) Title: IMPROVED THICKNESS MONITORING (57) Abstract <p>The thickness of a thin layer structure is monitored during deposition or etching. The structure is illuminated with a predetermined energy (visible or near visible light or x-ray) and a modified parameter of the illumination is measured, which may be reflection intensity, transmission intensity or polarisation. The detected signal is examined by shape recognition techniques using adaptive digital filters.</p>		

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1 "Improved Thickness Monitoring"

2

3 This invention relates to the field of thin film
4 deposition and/or removal, and more particularly to
5 improved monitoring of thickness during deposition or
6 removal using time domain image recognition applied to
7 optical reflectometry.

8

9 Thin films are commonly used to modify surface
10 properties. Typical applications include the coating
11 of optical components to improve their light
12 transmission or reflection properties, the coating of
13 composite materials to improve adhesion behaviour, and
14 the coating of semiconductors to introduce insulation
15 layers or layers with specific electronic properties.
16 Typically these thin films will have thicknesses in the
17 range of 1 nm to 5 μ m and are placed on top of a
18 substrate material which has a very much greater
19 thickness. Frequently the films are structured in
20 stacks, one on top of the other. Such stacks may
21 consist of three or four individual films up to
22 structures containing hundreds of films.

23

24 For adequately carrying out the function for which they
25 have been design d these films fr quently have to be

1 deposited or, once having been deposited, have to be
2 removed wholly or partially with very great precision.
3 This deposition or removal is frequently carried out
4 under conditions of a vacuum using heated elements and
5 gases or gases excited into the plasma state. Such
6 processes generate considerable quantities of noise in
7 electrical, thermal, optical, vibrational and radio
8 frequency categories.

9
10 Equipment that is measuring and/or controlling the
11 thickness and/or rate of deposited or removed film or
12 films therefore has to operate under arduous conditions
13 in the presence of many categories of interfering noise
14 signals. These interfering noise signals frequently
15 upset the measurement technique resulting in processes
16 that are inadequately controlled.

17
18 This invention improves the procedure of in-process
19 determination of the thickness of deposited or removed
20 film under these inherently noisy and difficult
21 conditions.

22 23 Background of the Invention

24
25 Thin film deposition or removal requires either
26 chemical or physical processes or a combination of the
27 two and most frequently takes place under conditions of
28 a partial vacuum. A typical film removal system to
29 which the equipment and method of the current invention
30 could be conveniently applied is depicted in Figure 1.

31
32 The method of film removal depicted here is commonly
33 referred to as dry etching or reverse sputter etching
34 depending on the pressure level maintained during the
35 process. The substrate 20 is placed on an electrode 21
36 which may be electrically isolated or part of the

1 electrical ground of the system. A second electrode 22
2 is connected to the opposite polarity of a power supply
3 unit 25. Commonly this is the positive polarity. The
4 system is enclosed within a vessel 23 which is
5 evacuated by a pumping means 24. The application of
6 power from the power supply 25 ionises residual gas in
7 the vessel or alternatively additional gases may be
8 introduced in order to modify the environment and the
9 process. The ionised gases are attracted to the
10 electrodes with the heavy positively charged ions
11 impinging on the substrate 20 causing film removal by
12 physical means and/or chemical means.

13
14 It will be readily observed from the foregoing
15 description and the drawing that the introduction of
16 any probe into the etch region will prevent ions from
17 impinging on the whole substrate and, if the probe is
18 metallic, disturb the electrical profile within the
19 etch region to the detriment of the process. As such
20 it is common and well known to introduce an optical
21 signal which is reflected off the substrate and
22 subsequently detected. A typical optical path is shown
23 at 28 with access to and egress from the system made
24 possible by transparent feed through ports or windows
25 26,27. An alternative system is to provide a small
26 window in the electrode 22 so that light can be
27 directed at the substrate and reflected back along its
28 own path.

29
30 An alternative arrangement for deposition rather than
31 removal of thin films is shown in Figure 2.

32
33 The method of film deposition depicted here is commonly
34 referred to as sputter deposition or plasma enhanced
35 chemical vapour deposition depending on the pressure
36 level maintained during the process. The substrate 30

1 is placed on an electrode 31 which may be electrically
2 isolated or part of the electrical ground of the
3 system. A second electrode 32 is connected to the
4 opposite polarity of a power supply unit 35. Commonly
5 this is the negative polarity. The system is enclosed
6 within a vessel 33 which is evacuated by a pumping
7 means 34. The application of power from the power
8 supply 35 ionises residual gas in the vessel or
9 alternatively additional gases may be introduced in
10 order to modify the environment and the process. The
11 ionised gases are attracted to the electrodes with the
12 heavy positively charged ions impinging on the chosen
13 material to deposit 39 which is placed on or bonded to
14 the electrode 32. Material is then deposited by
15 physical or chemical or a combination of methods on the
16 substrate 30. As a variant on this process there may
17 be no deposition material 39, with the deposition
18 occurring by a chemical combination of gases enhanced
19 by the plasma.

20

21 As with the previous case, it will readily be seen that
22 the introduction of a physical probe, such as may
23 consist of a quartz crystal microbalance, into the
24 deposition region will prevent depositing material from
25 impinging on the whole substrate and, if the probe is
26 metallic, disturb the electrical profile within the
27 etch region to the detriment of the process. As such
28 it is common and well known to introduce an optical
29 signal which is reflected off the substrate and
30 subsequently detected. A typical optical path is shown
31 38 with access to and egress from the system made
32 possible by transparent feed through ports or windows
33 36,37. An alternative system is to provide a small
34 window in the electrode 32 so that light can be
35 directed at the substrate and reflected back along its
36 own path. As an alternative if the substrate is

1 transparent then a small hole can be introduced in the
2 lectrode 31 with light transmitted through the
3 substrate, reflecting off the film deposited on the
4 front surface 40 and back along its own path.

5
6 Light that is introduced as described above reflects
7 off the film that is being deposited or removed and the
8 properties of the reflected light are modified (Ref
9 Born and Wolf). Such modification will occur to the
10 intensity of reflection and/or to the polarisation
11 properties and these modifications will depend on the
12 wavelength of the incoming optical radiation.
13 Determination of the film thickness can be by reference
14 to an existing reference standard (Ledger et al,
15 EP 0 545 738 A2) or alternatively oscillations in
16 reflected monochromatic light can be counted (Corliss,
17 GB 2 257 507 A). These methods can be improved by the
18 introduction of additional wavelengths (Canteloup et
19 al, EP 0 735 565 A1) where the additional wavelengths,
20 or indeed white light illumination with spectral
21 analysis of the reflection, is used to remove anomalies
22 in the identification of a particular oscillation
23 extremum.

24
25 Prior art assumes an idealised development of the
26 reflection process (Figure 3) with the change in film
27 thickness between extrema in the reflection signal (50)
28 occurring in a time ΔT being given by the relationship:

29
30
$$\Delta x = \lambda / (4\mu)$$

31
32 where Δx is the change in film thickness occasioning
33 the change in reflection level;

34 λ is the wavelength of the light used to probe the
35 film thickness; and

36 μ is the refractive index of the material at the

1 wavelength of light λ .

2

3 In real situations the signal frequently does not meet
4 this ideal and resembles the signal obtained and
5 illustrated in Figure 4.

6

7 The structure of the film giving this reflected signal
8 during its etch is shown in Figure 5. Here a metallic
9 mask 61 is overlying a film of silicon oxide 62 on a
10 silicon substrate 63 and the illumination beam 64 is
11 such that both the mask 61 and the exposed film are
12 illuminated. The idealised reflection profile (which
13 can be calculated as discussed below) is shown in
14 Figure 6. By comparing the idealised situation (Figure
15 6) with the practically experienced situation (Figure
16 4) a number of features are apparent.

17

18 Firstly there is the presence of wide bandwidth
19 noise.

20 Secondly there is a variation in the actual signal
21 variation between extrema (from maxima to minima).

22 Thirdly the fine detail structure in the trough at
23 each minimum has been completely masked.

24

25 It is the prime objective of this current invention to
26 provide a signal processing means to optimise the
27 acquisition of information from the signal of the type
28 shown in Figure 4.

29

30 Summary of the Invention

31

32 The invention in its broadest form provides an
33 apparatus and method for determining the thickness and
34 variation of thickness with time of thin films during
35 the process of their deposition, growth or removal, in
36 situ, under process conditions. The invention

1 comprises the steps of:

2

3 providing a means for reflecting or transmitting
4 light through or from a thin film structure whilst that
5 film structure is being processed to increase its
6 thickness, decrease its thickness or otherwise change a
7 property that relates directly or indirectly to its
8 optical properties;

9

10 at each point in time constructing an algorithm
11 for processing the changing optical signal by direct
12 reference to a set of calibration data, such set of
13 calibration data either having been previously acquired
14 from a calibration run of the process or, preferably,
15 generated from a physical model of the thin film
16 structure's development with thickness; the defining
17 essential of the algorithm being that it is not
18 sensitive merely to signal level but is highly
19 sensitive to development of the signal wave-form shape
20 with changing thickness; and

21

22 providing a means for indication of rate of change
23 of thickness (or other derived parameter) with time for
24 indication and control together with a means for
25 indication of thickness (or other derived parameter)
26 with time for indication, control and cessation of the
27 process.

28

29 In accordance with one embodiment of the invention a
30 helium neon laser is arranged to reflect off a
31 substrate that is covered with a thin film structure as
32 in Figure 1. The details of the thin film stack are
33 well understood from the previous deposition stages and
34 these details have previously been entered in to a
35 computer programme which analyses the idealised
36 modification of the reflected light with change in film

1 thickness. The etch process time is now divided in to
2 a series of epochs of time, the number and duration of
3 the epochs being chosen by reference to the rate of
4 change of shape and appearance of new features in the
5 idealised model. The idealised model falling within
6 each epoch of time is now analysed for shape content
7 by, conveniently, Discrete Fourier Transform analysis.
8 The information arising from the shape analysis is now
9 used for two purposes:

10

11 Firstly it is used to set up adaptive filters which are
12 therefore tuned to the response expected to be required
13 for the shape of the incoming signals during that epoch
14 of time.

15

16 Secondly it is used to track conformance to the
17 idealised signal shape by using techniques such as the
18 correlation technique. The correlation technique will
19 give a measure of match to the shape feature occurring
20 within the particular epoch of time and therefore by
21 reference to the idealised model thickness will be
22 derived.

23

24 It will be apparent to the skilled reader that this
25 method therefore eliminates DC signal drift, makes the
26 system immune to variations in the distance between
27 extrema, and the use of adaptively tuned filters helps
28 detect fine features in the presence of large amounts
29 of noise therefore maximising the data abstracted from
30 the process to the benefit of the user.

31

32 Description of the Drawings

33

34 Figure 1 illustrates a prior art film removal
35 system.

36 Figure 2 illustrates a prior art film deposition

1 system.

2 Figure 3 depicts an idealised development of the
3 refl ction intensity waveform with change in film
4 thickness, as assumed in the prior art.

5 Figure 4 depicts the same signal as typically
6 occurring in practice.

7 Figure 5 shows a mask and film structure giving
8 rise to the signal of Figure 4.

9 Figure 6 shows an idealised reflection profile for
10 the structure of Figure 5.

11 Figure 7 illustrates a thin film structure to be
12 etched by means of a first embodiment of the present
13 invention.

14 Figure 8 is a schematic diagram of an etching
15 system for carrying out the first embodiment.

16 Figure 9 is a flow chart illustrating data
17 processing carried out in the first embodiment.

18 Figure 10 illustrates a second embodiment of the
19 present invention.

20 Figure 11 shows a modified form of data comparison
21 which may be used in the foregoing embodiments.

22 Figure 12 shows a modified embodiment using
23 polarisation to generate a measurement signal for
24 processing.

25

26

27 Description of Specific Embodiments

28

29 Referring to Figure 7, a thin film structure is to be
30 etched half way through the thickness of the second
31 layer (counting the substrate as layer 0). The thin
32 film is to be defined in two dimensions by an overlying
33 mask which provides protection for the areas covered by
34 the mask. The mask material is conveniently made from
35 a material that only etch s slowly. In this sp cific
36 embodiment the overlying mask 70 is constructed from

1 photo-resist and the film is a six layer structure of
2 gallium aluminium arsenide of different concentrations
3 of aluminium overlying a gallium arsenide substrate 71.
4 The objective of this specific embodiment is to
5 terminate the etch process half way through the
6 penultimate layer 72.

7
8 The first step is to construct a set of reference data.
9 As discussed above, this is preferably accomplished by
10 establishing the effective impedance of the structure
11 as it is examined slice by slice with each slice being
12 thin compared to the overall thickness of an individual
13 layer. For example if the layer is 20 nm thick then
14 the size of a slice may conveniently be 0.1 nm.

15
16 So the modelling process (Ref: "Reflectance modelling
17 for in-situ dry etch monitoring of bulk SiO₂ and 3.5
18 multilayer structures", S.E. Hick, W. Parkes, J.A.H.
19 Wilkinson and C.P.W. Wilkinson, 1994, JVST, B-
20 12(6)3306) uses the standard transmission line theory
21 which indicates that at the sending end of a
22 transmission line terminated with a load impedance the
23 impedance Z_{in} is given by:

24
25
$$Z_{in}/Z_0 = \{Z_L + Z_0 \tanh(\gamma l)\} / \{Z_0 + Z_L \tanh(\gamma l)\}$$

26
27 Where

28 Z_0 is the characteristic impedance of the line
29 Z_L is the load impedance
30 γ is the complex propagation constant
31 l is the distance along the transmission line

32
33 The reflection coefficient is given by

34
35
$$\rho = \{Z_L - Z_0\} / \{Z_L + Z_0\}.$$

36

1 In the case of a film stack these equations become

2

$$3 \quad \{Z_{in}(l,m)\} / \{Z_o(l,m)\} =$$

$$4 \quad \{Z_L(m) + Z_o(m) \cdot \tanh(\gamma(m) \cdot l)\} / \{Z_o(m) +$$

$$5 \quad Z_L(m) \tanh((\gamma(m) \cdot l))\}$$

6

7 and

8

$$9 \quad \rho(l,m) = \{Z_{in}(l,m) - Z_{vac}\} / \{Z_{in}(l,m) + Z_{vac}\}$$

10

11 with

12

$$13 \quad \gamma(m) = 2\pi/\lambda \cdot j(n-jk)$$

14

15 and

16

$$17 \quad R(l,m) = |\rho(l,m)|^2$$

18

19 where m is the layer number with m=1 corresponding to
20 the layer directly above the substrate, Z_{vac} is the
21 impedance of free space, n and k are the real and
22 imaginary parts of the complex refractive index, R is
23 the reflectance, and j is the square root of minus 1.

24

25 In order to iterate the model:

26

$$27 \quad Z_L(m) = Z_{in}(X_m, m-1)$$

28

29 where X_m is the thickness of layer m and $Z_{in}(X_o, 0)$
30 corresponds to the substrate.

31

32 Therefore the model calculates the reflectance from a
33 wafer stack by considering the change in reflectance as
34 a single thin slice is added to the structure. When
35 the next thin slice is added the model considers the
36 impedance of the first slice/substrate combination to

1 be the impedance of the new combined "substrate". In
2 this way the reflectance as a function of film
3 thickness may be conveniently obtained for any
4 combination of layers.

5
6 The currently considered preferred embodiment also
7 contains a mask. This is modelled by considering the
8 reflection coefficients of the masked and unmasked
9 areas separately. The mask is also etched (although
10 normally the mask removal is much slower than the film)
11 and this may be allowed for again by modelling as a
12 function of thickness.

13
14 The result of the masked and unmasked areas is then
15 added for each "slice" in order to obtain the
16 reflection coefficient and thus the reflectance.

17
18 In this preferred embodiment (Figure 8) the etching
19 system consists of two parallel plate electrodes 80, 81
20 placed within an evacuated enclosure 82 which is
21 evacuated by a pumping system 83. The evacuated system
22 is then filled at low pressure with an etching gas
23 appropriate to the chemistry of the structure. In this
24 preferred embodiment this may be a freon such as methyl
25 chloride.

26
27 The substrate is placed on the bottom electrode 80
28 which may be connected to the ground of the system and
29 then to the negative pole of a radio frequency source
30 87. In the preferred embodiment this is a source at
31 13.56 MHz. The top electrode 81 is connected to the
32 positive pole of the RF source 87 and the application
33 of power creates a plasma which etches material of the
34 appropriate type placed on the bottom electrode 80.
35 The top electrode 81 has a small window 83 formed in
36 it. In the current embodiment the electrode 81 may be

1 about 20 cm in diameter and the window about 1 cm in
2 diameter and sealed with a transparent window of
3 material such as quartz. In the preferred embodiment a
4 helium neon laser 84 is then directed at the substrate
5 by means of a beamsplitter 85 prepared in such a way
6 that its reflectance and transmittance is 50%. The
7 reflected beam then passes the beamsplitter and the
8 intensity is sensed by a detector 86. In the preferred
9 embodiment the detector 86 may be a silicon photodiode.

10

11 Referring to Figure 9 which illustrates in flow-chart
12 form the data processing carried out in the preferred
13 embodiment, the idealised prediction of reflectance
14 against thickness 90 is scanned by a data window 91
15 which, in the preferred embodiment, may be a data
16 window extending to 1/3000 of the data size. The
17 contents of the data window 91 are then passed to a
18 software routine 92 that analyses frequency. In the
19 preferred embodiment this is a Fast Fourier Transform.
20 The output of the Fast Fourier Transform 92 is then
21 used to construct an adaptive digital filter 93 that
22 passes the frequencies present as being predicted to be
23 present in the data window 91 and highly attenuates
24 other frequencies. The output of the digital filter 93
25 is recorded as the processed signal against time 94.
26 It is a principal objective of the current invention
27 then to also use the digital filter 93 to carry out a
28 shape recognition 95 as compared to the idealised
29 prediction 90. In the preferred embodiment this shape
30 recognition 95 may be accomplished by a correlation of
31 the Fourier spectrum of the processed signal against
32 the Fourier spectrum of the idealised signal. The
33 output of the shape recognition 95 then yields a best
34 match which is the thickness 96 at any point in time of
35 the processed signal. This value is then compared to
36 the target thickness to give a termination On/Off

1 decision. Also this thickness value is compared at 98
2 to time to give a rat signal which may be used for
3 closed loop process control.
4

5 In a further specific embodiment, a thin film structure
6 is to be terminated part way through the thickness of
7 the layers but now there is inadequate knowledge of the
8 layer structure to allow a full idealised signal to be
9 produced by mathematical modelling. In this case
10 application of the present invention is achieved by a
11 calibration run. In Figure 10 the un-processed signal
12 output 100 of an etch of the structure is then
13 processed by a digital filter 101 using filter
14 parameters derived from keyboard entry 102. The output
15 of the digital filter 103 is then compared to any
16 predictive modelling or prior experience of film shape
17 to ensure that representative features are present.
18 This processed calibration run is then calibrated
19 against thickness by an off-line technique such as
20 stylus profiling. The resulting calibration data set
21 105 is then used in exactly the same way as the
22 idealised signal data set 90 in the previous preferred
23 embodiment.
24

25 The skilled reader will understand that the method for
26 analysing frequencies may be of many different types
27 such as cosine, sine or Laplacian methods. The skilled
28 reader will also understand that the shape comparison
29 technique may be achieved by many techniques including
30 Laplace Transforms and Gradiometer Transforms. The
31 data windows may also be of varying extent. Figure 11
32 shows one method of using data windows of different
33 extent. The data set 110 that is to be compared to,
34 which may be an idealised data set resulting from a
35 model or a calibration data set, is used in conjunction
36 with a range of data windows 111. These data windows

1 increase in length from one to the other so that if
2 confidence of recognition of shape by a correlation
3 technique using the Fast Fourier Transform or a
4 Laplacian Technique, or application of any other shape
5 recognition method such as the Gradiometer Transform,
6 falls below a pre-defined minimum level then the
7 subsequent increased size window may be used. Use of a
8 data window of increased size has the advantage of
9 allowing more data to be used to recognise features.
10 It has the concomitant disadvantage that more data has
11 to be present in the processed data stream to allow a
12 meaningful comparison but, since the movement to a
13 larger data window only occurs after more processed
14 data has been already collected, this disadvantage has
15 no impact on the availability of thickness data that is
16 the goal of the present invention. Under circumstances
17 where it is desirable for the confidence of fit to be
18 very high, for example close to the target thickness
19 for termination, it may be desirable to use data
20 windows only varying by a very small amount from each
21 other 112 and to automatically change from one data
22 window to the subsequent one rather than waiting for an
23 inadequate fit to be recorded.

24
25 In another preferred embodiment, Figure 12 shows the
26 incorporation of polarisation into the method. The
27 light source 129 is either polarised or a polarising
28 means 130 is used to ensure its polarisation state.
29 Upon reflection from the film stack the state of
30 polarisation is changed in a way that can be modelled
31 by application of transmission line theory or the
32 analysis of transmission of radiation using matrices.
33 Use of an analysing polariser 130 allows measurement of
34 the changed polarisation state to derive a signal
35 measurement. It will be apparent to the skilled reader
36

1 that the signal measured is now polarisation state
2 against time rather than reflectance against time.
3

1 CLAIMS

2

3 1. A method for determining the thickness of thin
4 films during the process of deposition or removal
5 of those thin films that comprises the steps of:

6

7 (a) illuminating the thin film with
8 electromagnetic radiation;

9

10 (b) detecting modifications in the property of
11 radiation that has been reflected or
12 transmitted by the film structure to generate
13 a measurement signal;

14

15 (c) producing a set of data predicting the signal
16 behaviour in advance;

17

18 (d) dividing the predicted signal behaviour into
19 one or more sets of data windows and using
20 the data windows of predicted signal
21 behaviour to form digital filters;

22

23 (e) using the derived digital filters to process
24 the measurement signal to form a processed
25 acquired signal; and

26

27 (f) using the processed acquired signal and the
28 predicted signal behaviour together with
29 shape recognition algorithms to derive a best
30 estimate of film thickness during the process
31 of film removal or deposition.

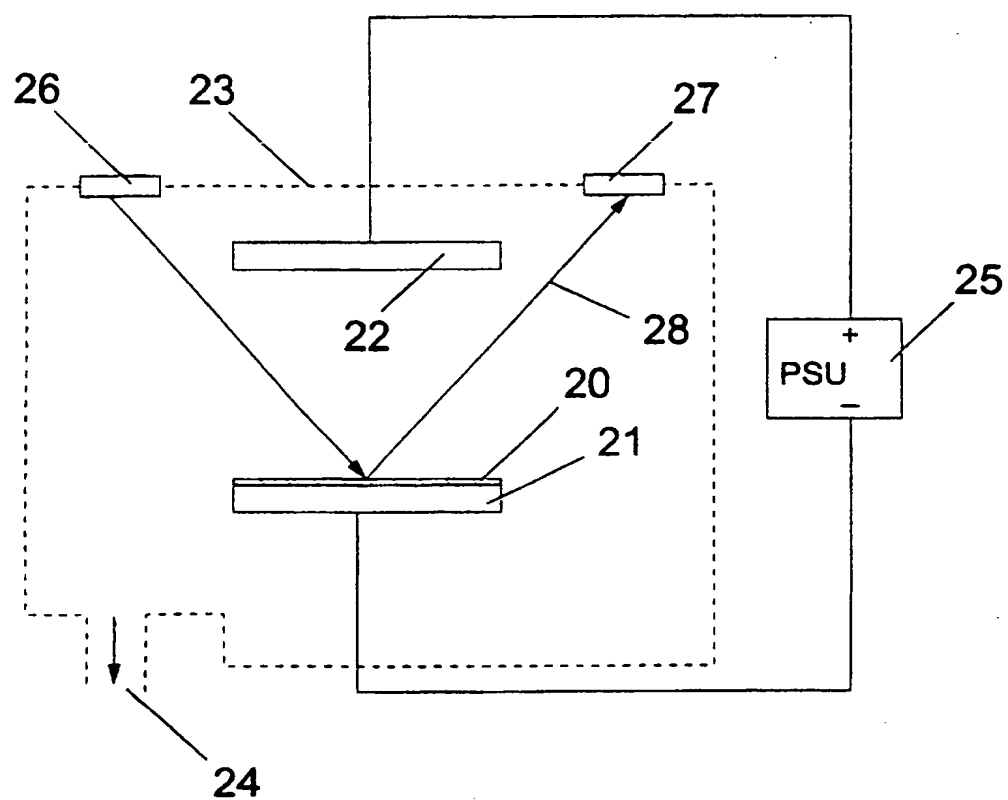
32

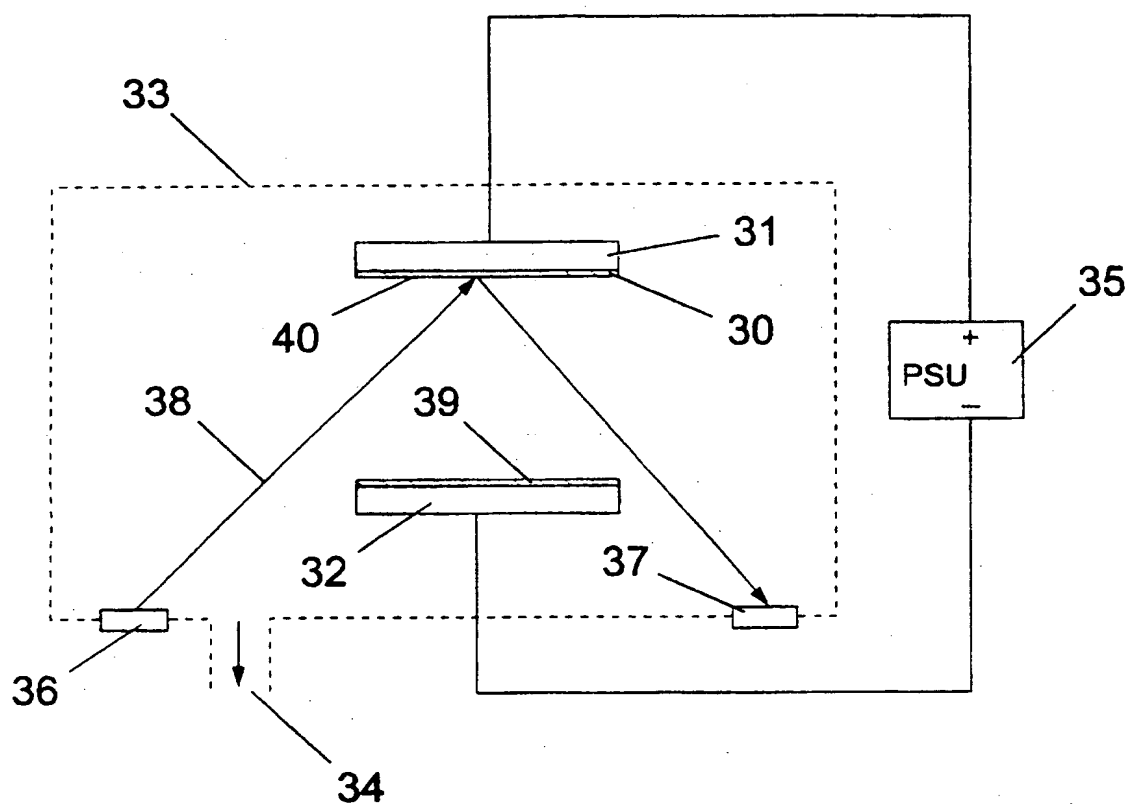
33 2. The method of Claim 1, wherein the predicted data
34 is derived by the application of iterations of
35 reflections at an effective complex load
36 impedance.

- 1 3. The method of Claim 1, wherein the predicted data
2 is derived by the application of matrix modelling
3 to wave propagation through the film structure.
4
- 5 4. The method of any preceding claim, wherein the
6 shape analysis is carried out by application of
7 the Fourier Transform.
8
- 9 5. The method of any of claims 1 to 4, wherein the
10 shape analysis is carried out by application of
11 the Laplace Transform.
12
- 13 6. The method of any of claims 1 to 4, wherein the
14 shape analysis is carried out by application of
15 the Gradiometer Transform.
16
- 17 7. The method of any preceding claim, wherein the
18 predicted signal behaviour is obtained by
19 calibration using a calibration run of a film
20 structure similar or identical to that which it is
21 required to process.
22
- 23 8. The method of any preceding claim, wherein the
24 data window size is not fixed but is changed
25 dynamically depending on the detail of shape
26 structure predicted to be present at any point in
27 the process or is increased monotonically with
28 time.
29
- 30 9. The method of any preceding claim, wherein the
31 modification to the property of the incident
32 radiation is polarisation.
33
- 34 10. The method of any of claims 1 to 8, wherein the
35 modification to the property of the incident
36 radiation is intensity.

- 1 11. The method of any preceding claim, wherein the
2 illumination is broad-band and contains many
3 wav lengths.
4
- 5 12. The method of any of claims 1 to 10, wherein the
6 illumination is narrow band.
7
- 8 13. The method of any preceding claim, wherein the
9 illumination is in the visible part of the
10 spectrum.
11
- 12 14. The method of any of claims 1 to 12, wherein the
13 illumination is in the ultraviolet part of the
14 spectrum.
15
- 16 15. The method of any of claims 1 to 12, wherein the
17 illumination is in the x-ray part of the spectrum.
18
- 19 16. The method of any preceding claim, wherein the
20 illumination is at 90° to the plane of the
21 substrate.
22
- 23 17. The method of any preceding claim, wherein the
24 illumination is at less than 90° to the plane of
25 the substrate and the angle is entered as a
26 variation in the mathematical model to predict the
27 idealised signal.
28
- 29 18. Apparatus for carrying out the method of claim 1,
30 the apparatus comprising:
31 means for illuminating a thin film structure
32 with electromagnetic radiation while the structure
33 undergoes deposition or removal;
34 means for detecting modifications in the
35 prop rty of radiation that has been reflected or
36 transmitted by the film structure to generate a

1 measurement signal;
2 computing means arranged to receive the
3 measurement signal and to process it by:
4 (a) forming a processed acquired signal by
5 filtering the measurement signal using
6 digital filters derived from a predicted
7 signal behaviours divided into data windows,
8 and
9 (b) deriving a best estimate of film
10 thickness during processing of the film
11 structure by applying shape recognition
12 algorithms to the processed acquired signal
13 and the predicted signal behaviour.

*Fig. 1*

*Fig. 2*

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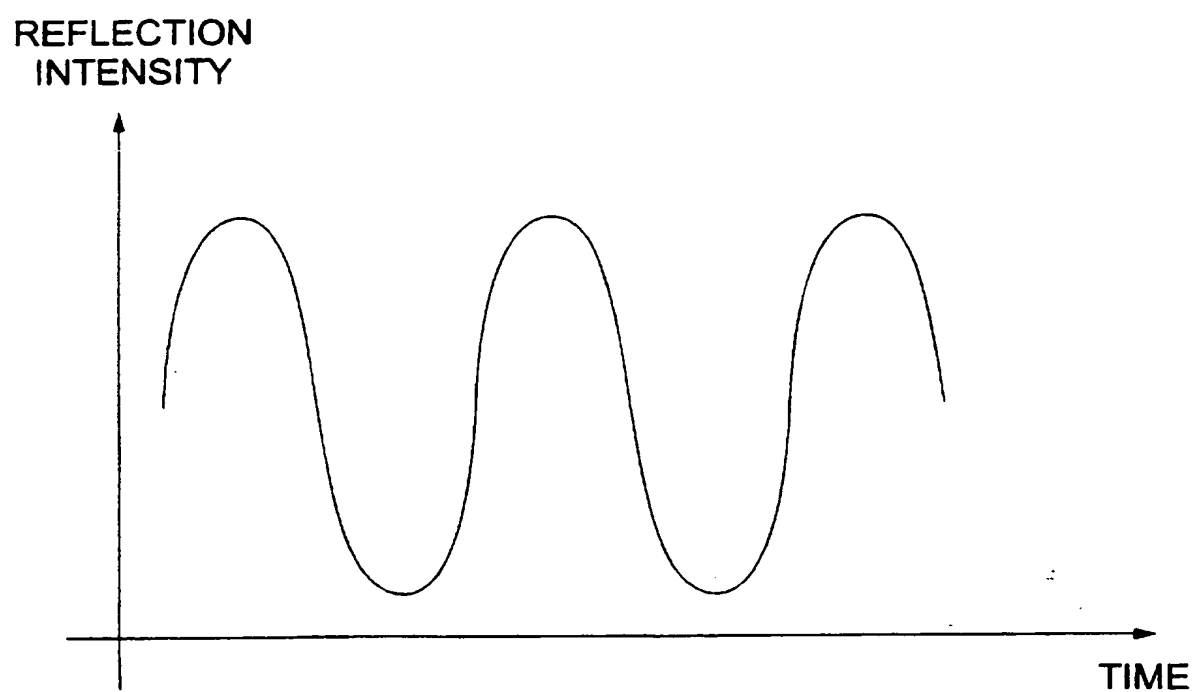
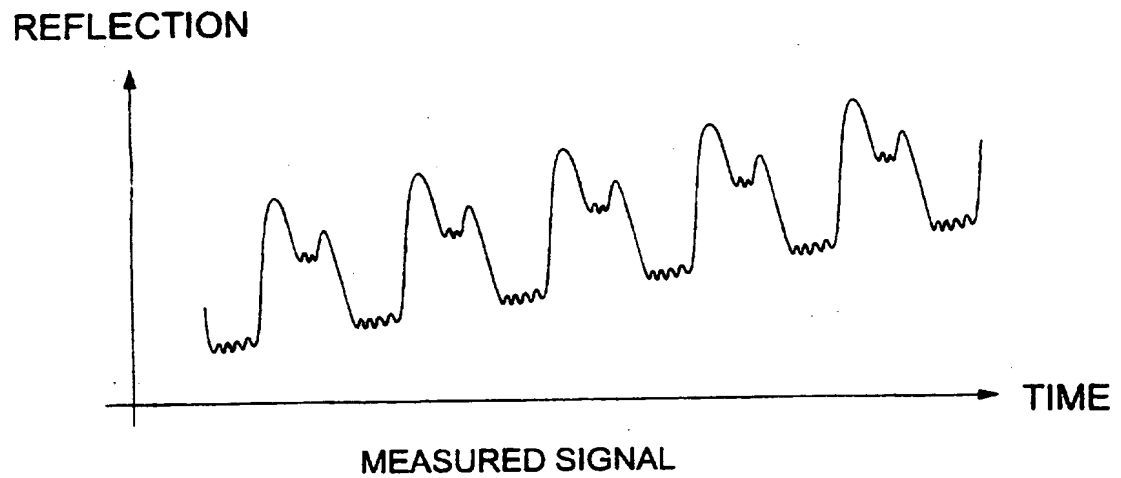
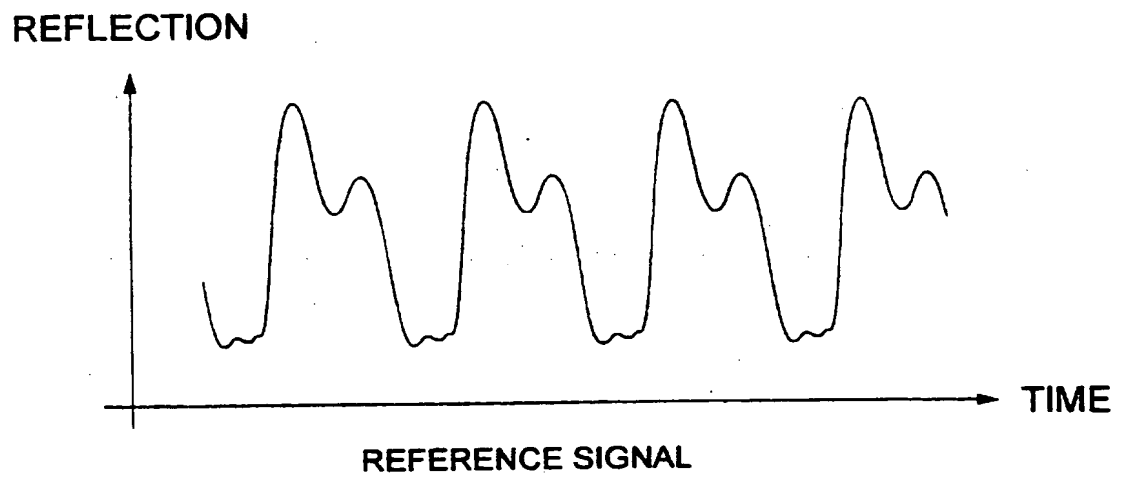
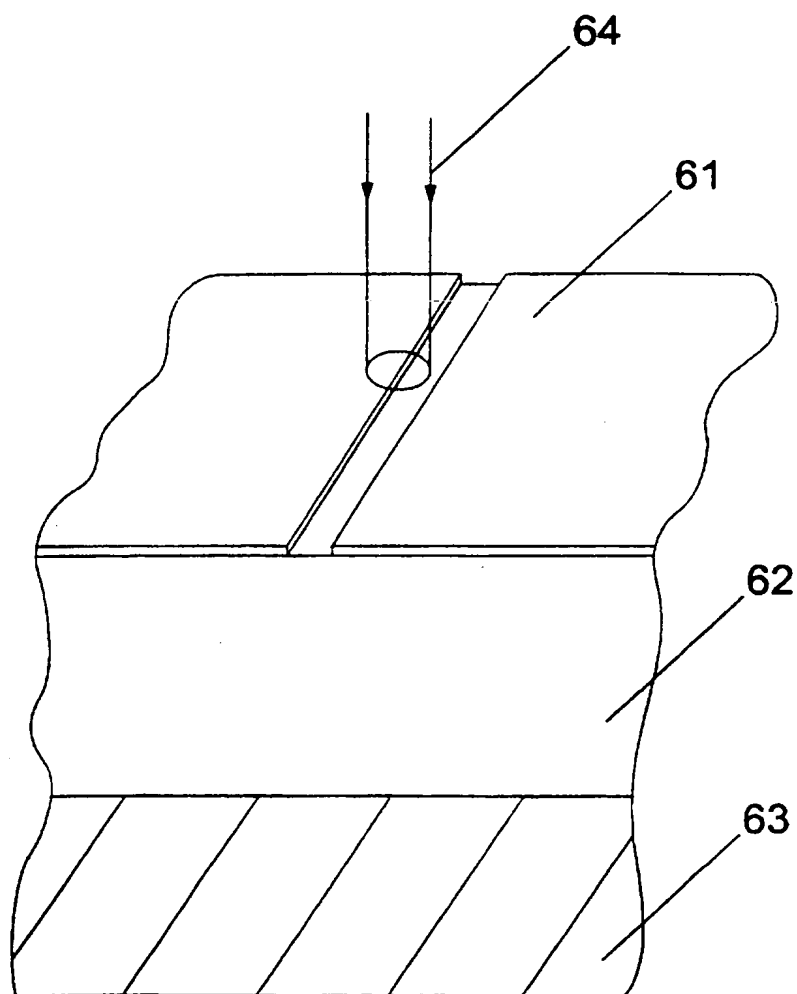


Fig. 3

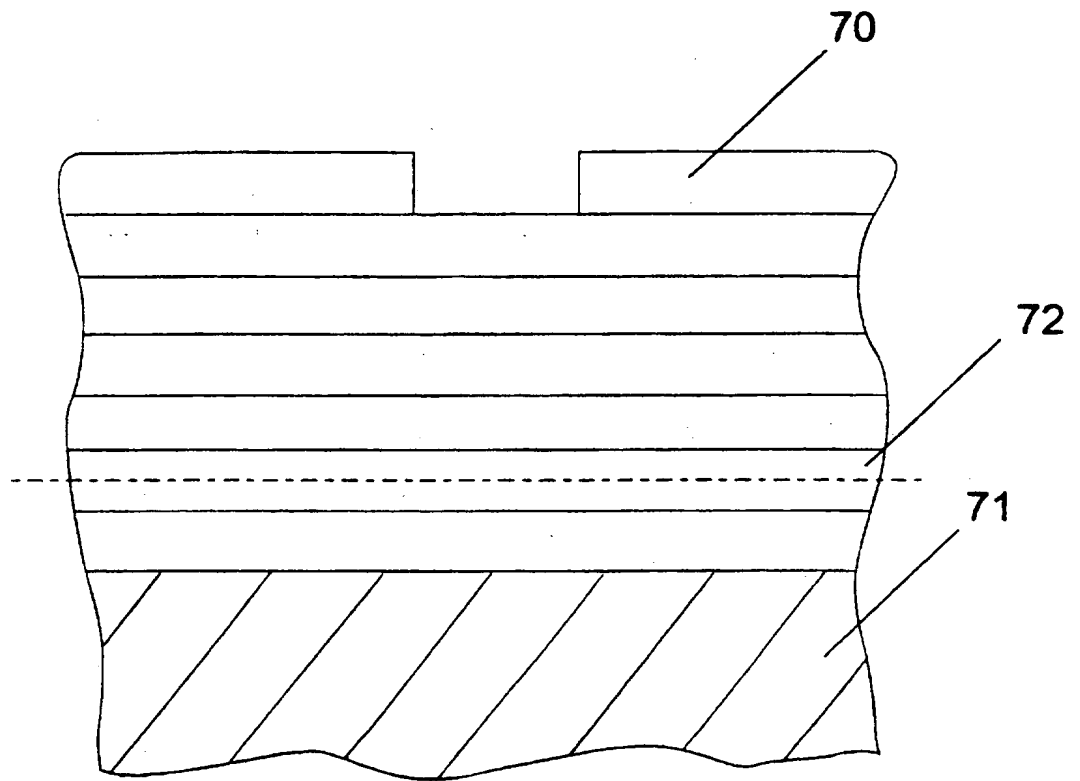
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*Fig. 4**Fig. 6*

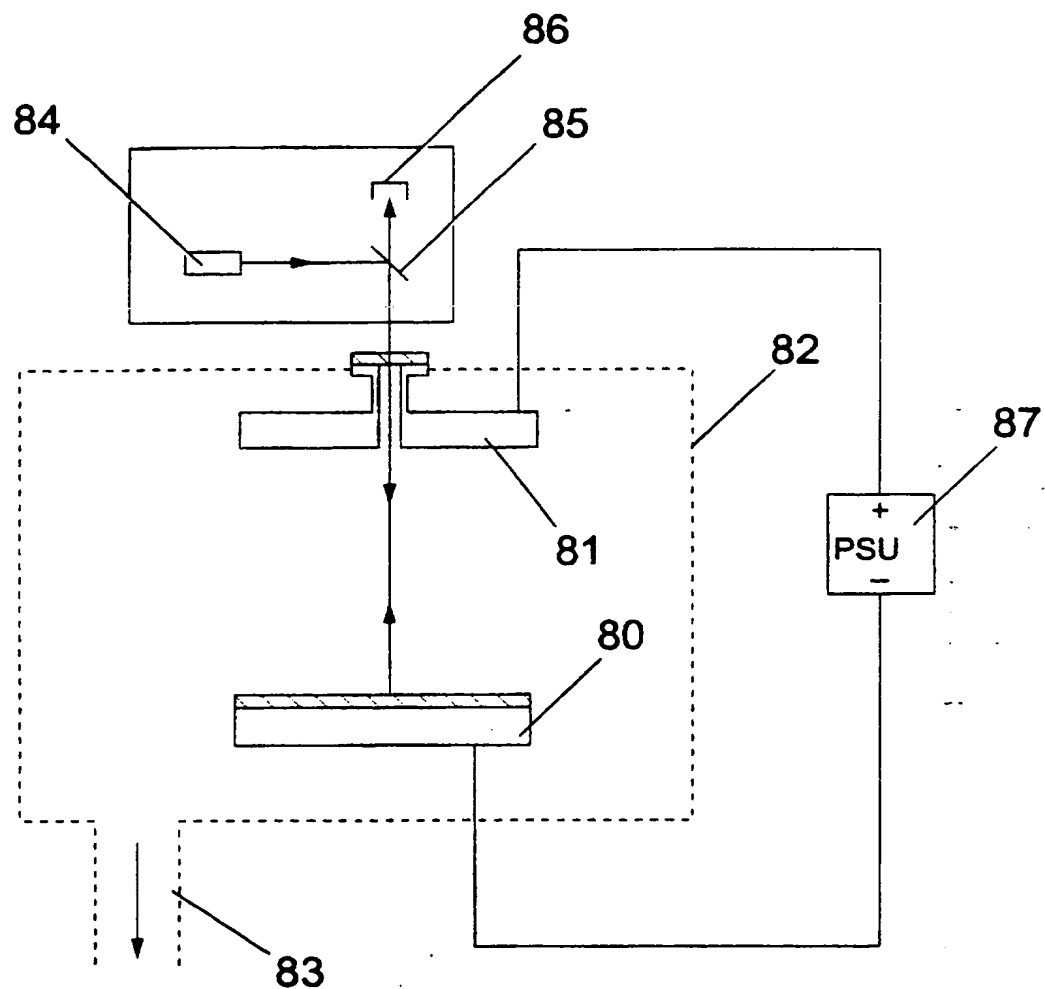
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*Fig. 5*

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*Fig. 7*

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*Fig. 8*

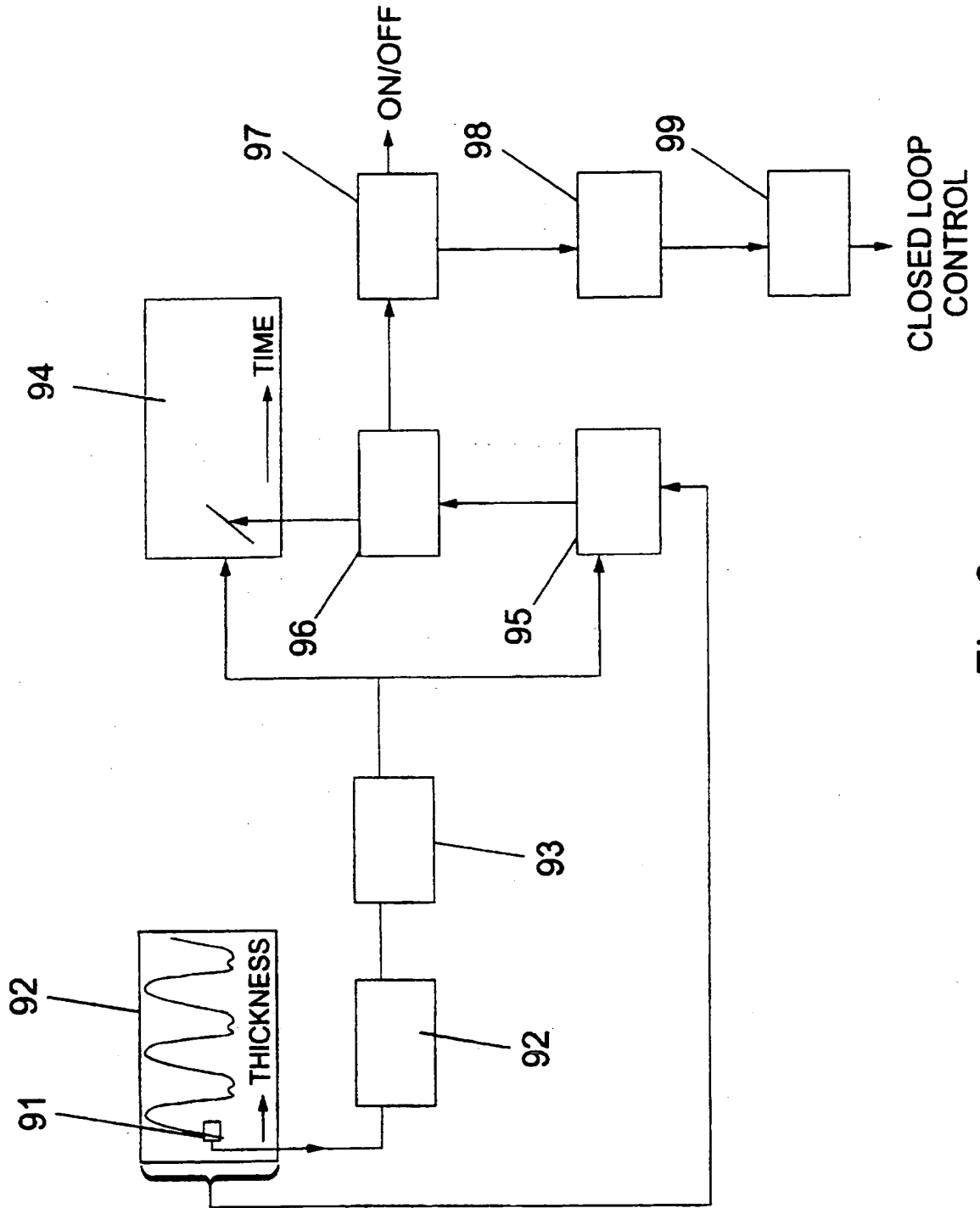
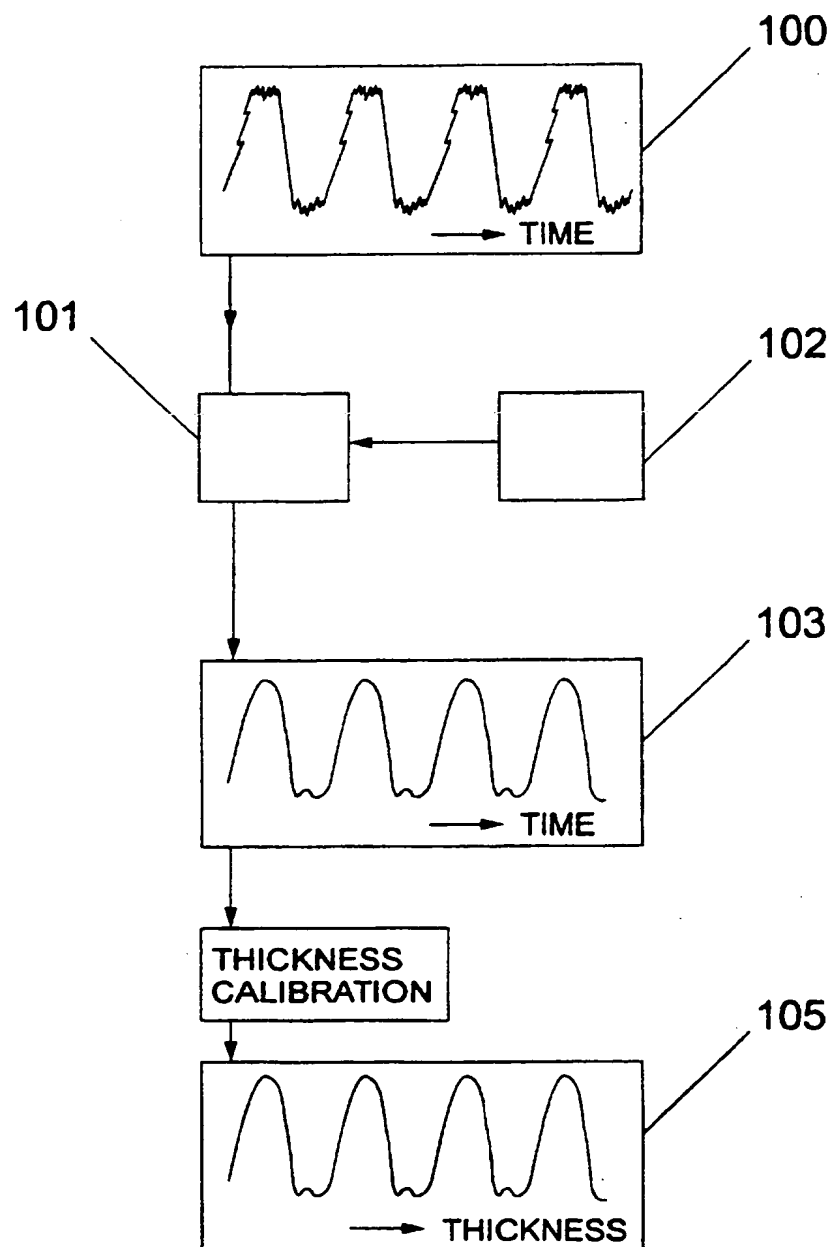


Fig. 9

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*Fig. 10*

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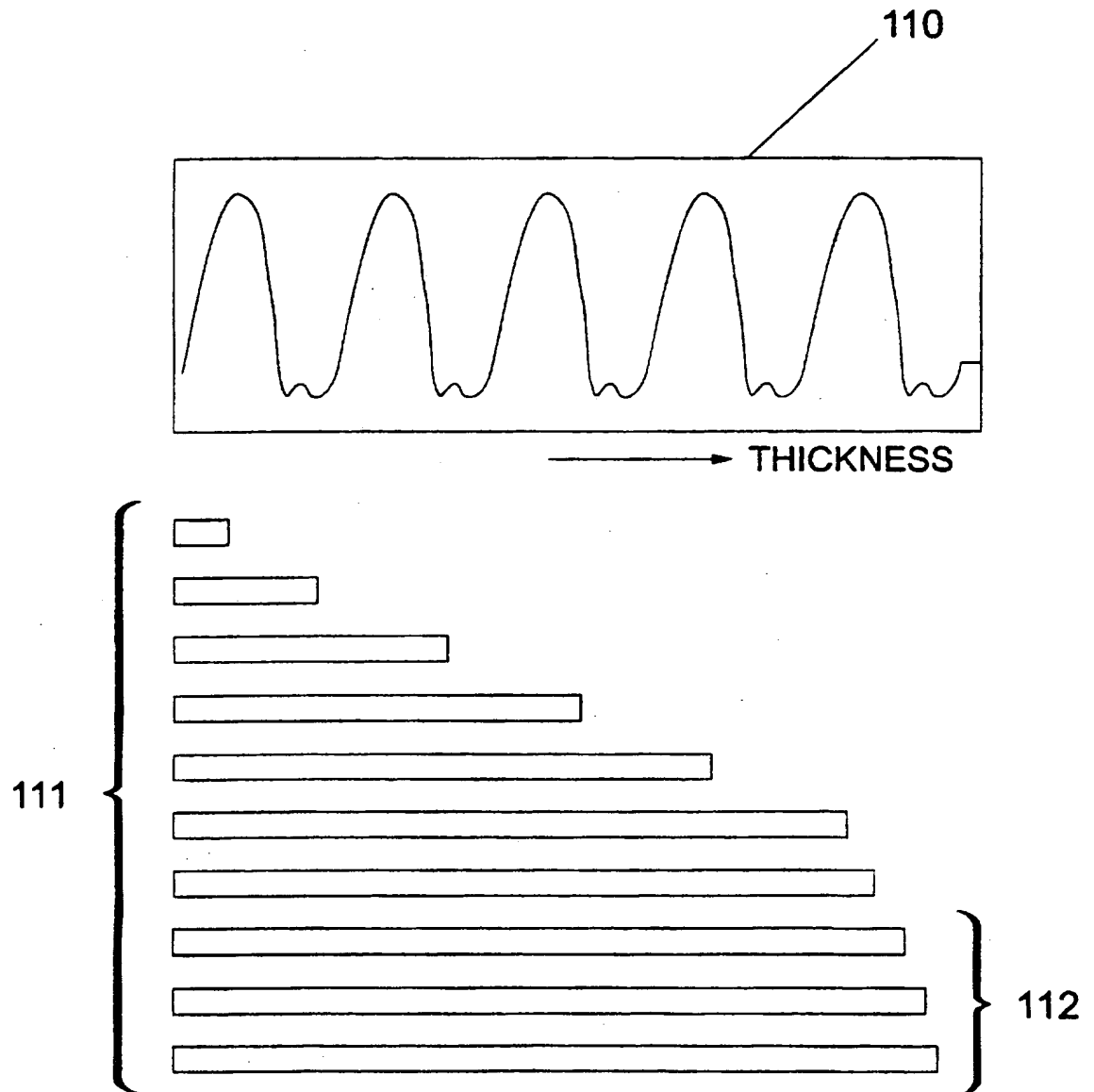
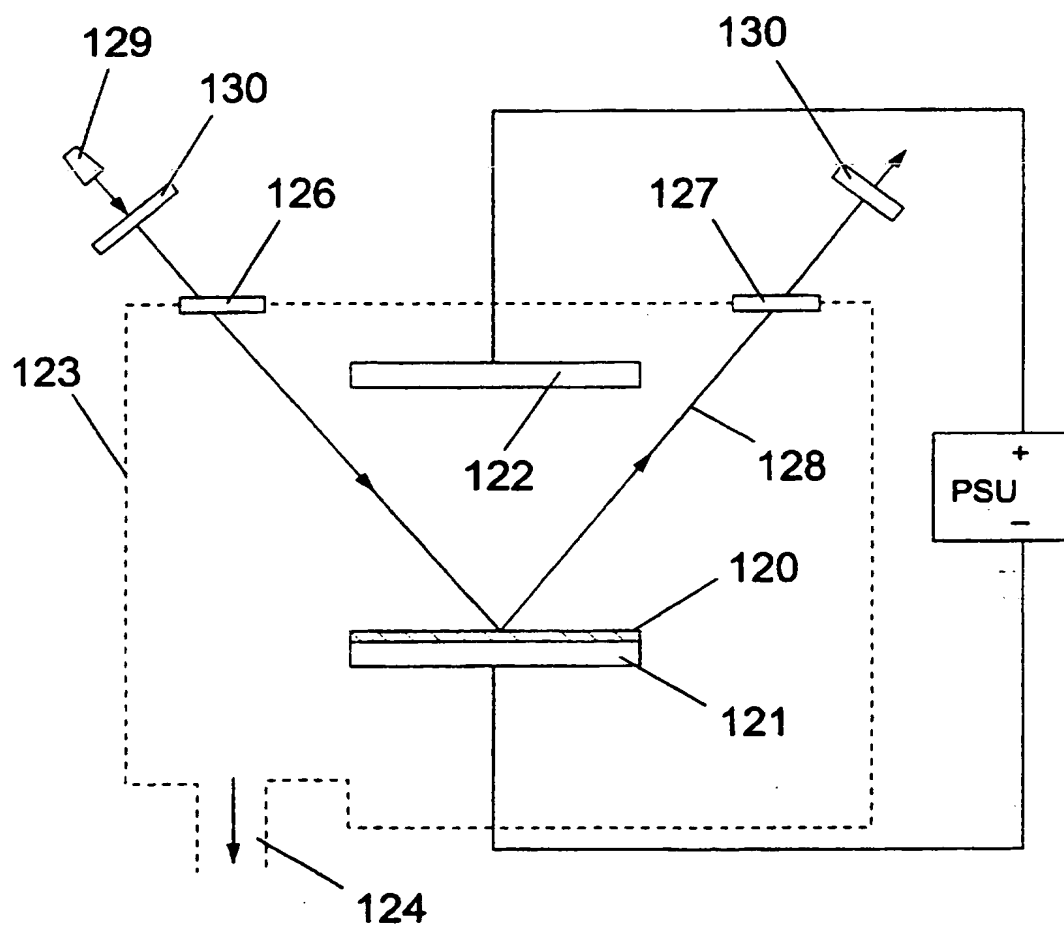


Fig. 11

*Fig. 12*

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 97/02139A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 G01B11/06

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 G01B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	HICKS S E ET AL: "REFLECTANCE MODELING FOR IN SITU DRY ETCH MONITORING OF BULK SiO ₂ AND III-V MULTILAYER STRUCTURES" JOURNAL OF VACUUM SCIENCE AND TECHNOLOGY: PART B, vol. 12, no. 6, 1 November 1994, pages 3306-3310, XP000497155 cited in the application see the whole document ---	1,18
A	EP 0 690 288 A (HASSBJER MICRO SYSTEM AKTIEBOL) 3 January 1996 see abstract; figure 1 ---	1,18
A	EP 0 650 030 A (MITSUBISHI ELECTRIC CORP ;JASCO CORP (JP)) 26 April 1995 see abstract; figure 11 ---	1,18
-/-		

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- 2 12 97

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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 0 631 106 A (MITSUBISHI ELECTRIC CORP) 28 December 1994 see abstract; figure 2 ---	1,18
A	EP 0 644 399 A (DAINIPPON SCREEN MFG) 22 March 1995 see abstract; figure 2 -----	1,18

INTERNATIONAL SEARCH REPORT

Information on patent family members

Patent Application No

PCT/GB 97/02139

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 0690288 A	03-01-96	SE 502239 C SE 9402247 A US 5581354 A	18-09-95 18-09-95 03-12-96
EP 0650030 A	26-04-95	JP 3110405 A JP 4120404 A DE 69021813 D DE 69021813 T EP 0420113 A US 5227861 A	10-05-91 21-04-92 28-09-95 23-05-96 03-04-91 13-07-93
EP 0631106 A	28-12-94	JP 7004922 A US 5523840 A US 5587792 A	10-01-95 04-06-96 24-12-96
EP 0644399 A	22-03-95	JP 7091921 A US 5493401 A	07-04-95 20-02-96